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EVALUATION OF TECHNIQUES FOR LOCATING LEAKS IN
UNDERGROUND HEAT DISTRIBUTION (U) CONSTRUCTION
ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL

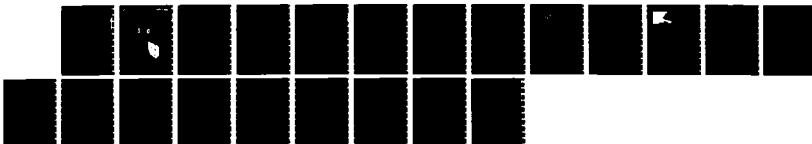
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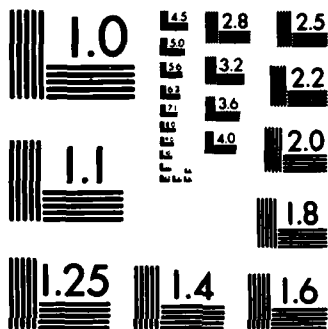
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TECHNICAL REPORT M-86/16
August 1986
Underground Distribution Systems

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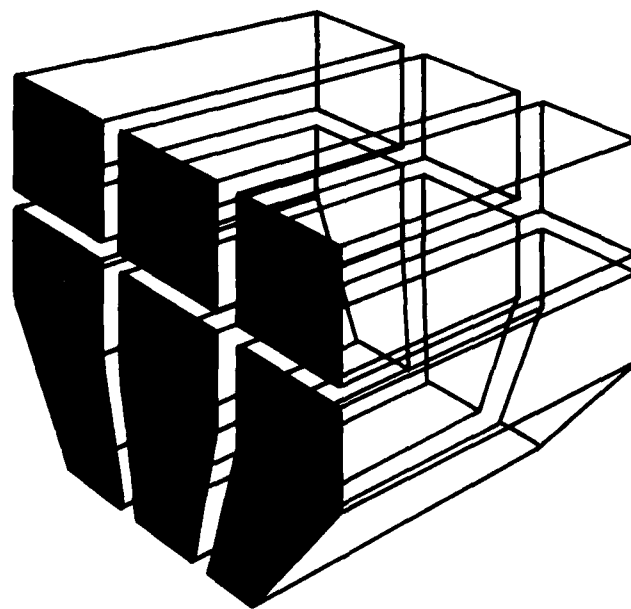
Evaluation of Techniques for Locating Leaks in Underground Heat Distribution Systems

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by
Kirk E. Cooper
Charles Marsh
Ellen G. Segan

This report evaluates techniques for locating leaks in both conduit and carrier pipes of Class A prefabricated heat distribution systems and shallow trench systems. Techniques discussed include infrared spectroscopy, tracer gas, and acoustic emission. Available techniques were reviewed for their success in locating leaks at various sites and for the cost of equipment and services they require.

The probability of locating leaks with a given technique is a function of many factors, including system configuration, type of leak, depth of system burial, and other environmental factors. A flowchart was developed to help select an appropriate leak location technique for a given system. Accuracy of leak location may be excellent in some cases, but poor in others. The factors that impede accurate leak location using the various techniques investigated are also discussed.



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FOREWORD

This study was performed for the Office of the Chief of Engineers (OCE) under the Operations and Maintenance, Army Work Unit "Underground Distribution Systems." The work was performed by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). The OCE Technical Monitor was Mr. Dale Otterness, DAEN-ECE-E.

Dr. R. Quattrone is Chief of USA-CERL-EM. COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.



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EVALUATION OF TECHNIQUES FOR LOCATING LEAKS IN UNDERGROUND HEAT DISTRIBUTION SYSTEMS

1 INTRODUCTION

Background

The Department of Defense (DOD) maintains an estimated 6000 miles of heat distribution lines, most of which are underground. Energy loss and reductions in component lifetimes due to system leaks have become a concern. According to a recent report,¹ the 1985 cost of rebuilding these steam and high-temperature hot water (HTHW) lines would be about \$9.5 billion.

An alternative would be replacement/repair of only leaking or damaged sections of line, but this is also expensive. For example, in FY83 Army costs for real property maintenance of steam and hot water distribution systems was \$33 million.²

In the past, operators of Class A³ prefabricated systems have not had enough information to determine the most efficient course of action in locating and repairing leaks. The energy consumption of leaking underground heat distribution systems can be extremely large, so leaks should be located and repaired promptly. However, to date, there has been no consolidation of techniques for locating leaks in prefabricated lines.

Leaks that occur in shallow trench systems—another type of underground system—should also be repaired promptly. As in aboveground systems, no sophisticated techniques are needed to help locate these leaks. However, the economics of random or systematic removal of slabs to locate these leaks have not been investigated to date.

Objective

The objectives of this study were to (1) evaluate available technologies for locating leaks in underground

heat distribution systems, (2) investigate the uses and limitations of these methods, and (3) provide an effective scheme for selecting an optimal leak location method(s) for a specific situation.

Approach

The three most widely used techniques as well as several less common approaches for detecting and locating leaks in Class A heat distribution systems were investigated. The scientific principles on which the techniques are based, previous leak location studies, and available products and services for conducting leak surveys were reviewed. A flowchart for helping the operator of a heat distribution system select a leak location technique was then prepared.

Mode of Technology Transfer

The results of this study will impact operating and maintenance procedures for underground heat distribution systems as well as the revision of Corps of Engineers Guide Specification (CEGS) 15705, *Underground Heat Distribution Systems*; Naval Facilities Engineering Guide Specification 15705, *Underground Heat Distribution Systems*; Air Force Pamphlet 88-44, *Underground Heat Distribution Systems*; and CEGS 15709, *Heat Distribution Systems Outside of Buildings—Concrete Shallow Trench Systems*.

2 CONFIGURATION OF HEAT DISTRIBUTION SYSTEMS

Prefabricated Conduit Systems

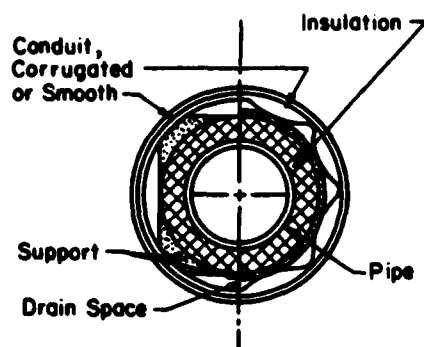
The prefabricated steel conduit systems approved for use at DOD installations (see Figure 1) present some unique leak location problems. Two types of Class A systems are approved for DOD use: the drainable and drible type and the water spread limiting type. In these systems, the insulated heat-carrying pipe is supported inside the protective smooth or corrugated conduit, with a 1-in. (25.4-mm) minimum annular air space required between the outside of the insulation and the conduit interior wall. A sandwich construction of mastic/fiberglass/mastic/roofing paper (felt) waterproofs the conduit's exterior surface. The supply and return lines may be either in a common conduit or in separate conduits.

Leaks can occur in the conduit, in the carrier pipe, or both. There are several possible causes of leaks, including corrosion, mechanical rupture (e.g., due to soil settling, pipe expansion), and construction deficiencies

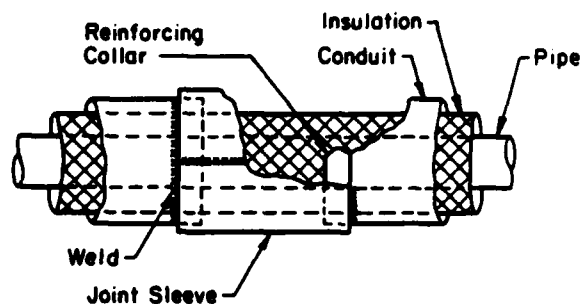
¹ *Heat Distribution Systems Life Cycle Cost Analysis, Preliminary Report*, Report 130319 (PanAm World Services, Inc., April 1985), p 4.

² *Facilities Engineering Annual Summary of Operations, Vol II: Army-wide Commands/Installations Performance, Fiscal Year 1983* (Department of the Army, Office of the Chief of Engineers, 1984).

³ *Corps of Engineers Guide Specification (CEGS) 15705, Underground Heat Distribution Systems* (August 1984), p 24.



Typical Cross Section



Typical Field Joint

Figure 1. Typical design of the prefabricated conduit system.

(e.g., poor welds, improper cold-springing of expansion loops). Accurately locating these leaks for repair or replacement of damaged components is extremely difficult. By the time that line pressure drops or reduced heat supply to an area indicate a leak, there has already been significant damage to the system. Other manifestations of leaks are pooling water, melted snow, or burned grass above the lines, which may not occur at the exact location of the leak. Attempts to locate leaks in conduit systems by other, nonvisual techniques has yielded various results; to date, however, the effectiveness of these methods has not been summarized.

Shallow Concrete Trench Systems

An alternative heat distribution system approved for use in Class B areas⁴ is the shallow concrete trench system (see Figure 2). A concrete trench with removable concrete top slabs contains insulated supply and return lines. Pipes are either supported by floor steel roller guides or by U-bolt hangers. The concrete cover slabs can be used as a sidewalk and lifted off to facilitate repair of the piping. Use of the shallow trench construction largely avoids the problems of corrosion failure associated with direct-buried systems. Elimination of the casing also reduces the amount of pipe that can develop leaks.

⁴CEGS 15705.

3 ASSESSMENT OF LEAK LOCATION METHODS AND AVAILABLE PRODUCTS

Leak Location Methods

Various techniques have been used to try to pinpoint leaks in HTHW or steam systems. The "hit and miss" method of excavating large portions of line has often been used, guided only by such external indicators as pooling water, burned grass, or melted snow. Large-scale excavation is expensive, imprecise, and time-consuming. Another technique that some operators have actually used is "water witching"—using a divining rod to locate water leaks. Despite claims of success, testing of this technique to locate leaks in these systems yields spurious results. Other, more commonly used methods are discussed below.

Infrared Spectroscopy

Infrared (IR) spectroscopy is used to take a temperature profile of the ground above the pipeline. Either repeated use of a digital temperature reading device or a sophisticated imaging system will locate "hot spots."

IR analysis of underground heat lines presents some strong advantages over other popular methods of leak detection/location. The video image can be manipulated to make it easier to see and interpret. Systems can operate uninterrupted, and do not require shutdown as with tracer gas procedures. A complete record of the

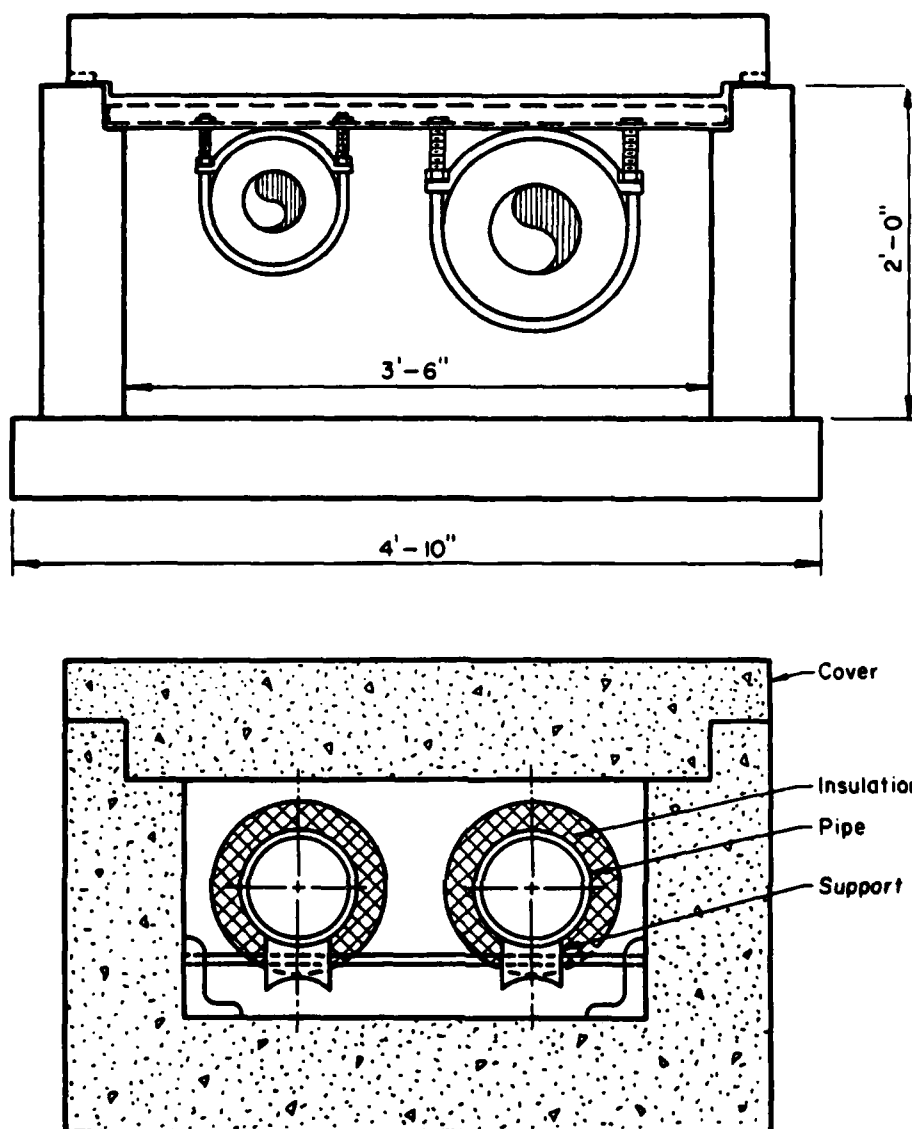


Figure 2. Typical design of the concrete shallow trench system.

pipng condition is obtained in a single scan, whereas multiple readings are often necessary with techniques such as acoustic emission. Deviations of lines from paths where they are supposed to be are also readily detected from IR scans.

A drawback of this method in locating leaks in HTHW systems is that the leak source may be blurred when the hot water spreads into the surrounding soil. Depending on the soil type and conditions, leaking HTHW could back up to higher elevations or be absorbed, particularly in sandy soil. In either case, accurate location of the leak with IR methods is difficult.

The ideal case would be when a leak occurs in both the carrier and conduit pipes (see Figure 3) at the same location. However, there is limited accuracy when any of the following situations occur:

1. There is a leak in only the conduit or carrier pipe.
2. Multiple leaks are present in either the conduit or carrier.
3. The conduit and carrier leaks are at different locations.



Figure 3. Example of a leaking conduit system.

4. Leaking pipes are buried so deeply that IR signals are grossly attenuated by the soil or other ground cover, such as water or snow.

Another drawback of the IR method is its high cost. A basic imaging system currently costs between \$15,000 and \$50,000. The cost of using a contractor to perform a single IR imaging leak survey of a military base may exceed \$10,000, not including excavation and replacement/repair costs. In contrast, the base price of IR thermometers is \$800 and \$1500. However, even under good conditions, the ability of the IR thermometer to give an accurate temperature profile in a reasonable amount of time is questionable.

Tracer Gas

Several methods that use gas to detect and locate leaks have been proposed. The widespread use of these techniques to locate leaks in pressurized underground telephone and high-voltage cables is evidence of their effectiveness.

Gas is introduced into the pipe system, and its concentration is measured with a dedicated gas chromatograph or ion-capture device at the ground surface or in shallow seepage holes along the pipe. A gas that does not occur naturally, such as sulfur hexafluoride (SF_6), is often used to avoid erroneous readings caused by the presence of gases already in the atmosphere and soil.

Tracer gas leak location seems to be a feasible method for the double-walled pipes used at DOD installations. A procedure for detecting leaks in both the conduit and carrier pipes has been proposed by industry. This method involves testing for a leak in the inner pipe by pressurizing with tracer gas while a flow of air is maintained in the annular space between

the carrier and casing. A leak is indicated when a mass spectrometer detects tracer gas at the far end of the outer pipe.

To pinpoint the location of this leak, the inner pipe is cleared of tracer gas with an airflow, and the outer pipe is pressurized with gas until a low and steady concentration is observed from the end of the inner pipe. The air flow is restarted, and the time it takes for the gas to first be detected on the spectrometer is monitored closely. Knowing this amount of time, the air flow rate, and the pipe's diameter, one can calculate the distance to the leak. As a check, the spectrometer and air pump positions are reversed and the process is repeated.

Leaks in the casing are located by pressurizing the conduit with tracer gas and scanning the ground surface for evidence of diffused gas. Since direct vertical diffusion to the surface is often inhibited by soil variations or obstructions, greater accuracy in pinpointing leaks can be obtained by digging small holes at regular intervals along the pipe in the area of highest gas concentration. The air in each hole is then checked for accumulated gas, with the hole having the highest concentration usually indicating the leak location.

Another technique involves a flame ionization detector (FID) to register the presence of hydrocarbons. This method is often used in natural gas pipelines, but could also be adapted to leak detection/location in heat distribution lines. The gas used contains a combustible hydrocarbon, which upon reaching the detector cell, is ionized by a flame that produces a small current flow between the cell wall and the internal collector. The current flow is proportional to the amount of hydrocarbons present in the sample. One manufacturer of FIDs has noted that factors such as weather, line pressure, pipe depth, soil type and moisture content, surface condition, and paving all affect venting of the gas to the surface and must be considered.⁵

Although the tracer gas technique is promising for locating leaks in double-walled piping systems, it has several limitations. The gas could preferentially migrate down the outside of the conduit where there is likely to be less resistance to flow. Differences in gas diffusion rates through various soils and ground covers may also result in erroneous leak location readings. Use of a combustible gas, as for FIDs, is often prohibited

⁵DP II *Instruction Manual* (Heath Consultants, Inc.), p 23.

because of the danger of explosion. Another major drawback of the tracer gas method is that the system must be shut down when the carrier pipes are tested for leaks. Systems could remain operational if only conduit leaks were sought, since conduit access is gained through vent or drain plugs in manholes; however, since distances between manholes can be up to 500 ft (150 m), and since expansion loops are often present, calculating the time for gas to travel down the pipe for locating leaks becomes complicated. Also, a single system test would not detect multiple carrier leaks, so that location and repair would have to be done for each leak—a rather time-consuming and expensive effort. The scheme outlined for conduits above may also have to be modified if there are leaks in both the conduit and carrier pipes.

Acoustic Emission

When pressurized hot water or steam escapes from an orifice at a sufficient rate, some of the energy dissipated in the turbulent flow takes the form of acoustic waves. These waves are omnidirectional and, aside from interfaces, decrease in intensity inversely with the square of the distance from the source. This sound generation is affected by the density, flow rate, viscosity, receiving medium, and length of the leak channel. The ratio between the useful signal amplitude and background noise levels has a maximum value in the near ultrasonic range. Thus, most commercially available instruments for leak location that use acoustic emission operate in this frequency range. Instrument components usually include a sensitive signal pickup device, an electronic amplifier, and one or more band-pass filters varying widths in the 30- to 60-kHz range.

Acoustic signals can be detected in several ways. Direct contact with the pipe is made by touching the sensing microphone to an accessible point or fitting on the pipe. Alternatively, a metal rod used as an acoustic waveguide can be driven through the soil and conduit coatings to establish metal-to-metal (rod-to-conduit) contact. Listening to leak sounds at the ground surface will also allow leaks to be located but the signal received at the surface is a lower-frequency, lower-intensity signal. Leaks are localized by determining the point at which the leak noise is most intense.

A relatively new technique using acoustic correlation has been successfully employed⁶ to detect

and locate leaks in pressurized water systems. This method overcomes the limitations encountered from noisy environments, deeply buried pipe, or transmission of leak noise through an indirect path. Correlation of acoustic signals to locate leaks uses the following three properties of leak noise:

1. It is random over time.
2. Its propagation in a pipe occurs at the same speed throughout the pipe's length.
3. In contrast to many transitory background noises, it is permanent over time.

The correlation principle involves finding a similarity between signals resulting from leak noise at two different points on a pipe by subjecting the signals to a series of time shifts. The leak is located by identifying the shift that exactly compensates for the difference in propagation times from the leak to the two pipe access points. As in the traditional method of acoustic leak detection/location, adequate training of inspecting personnel is essential to obtain accurate results; moreover, the computerized equipment needed to perform the correlations is expensive. Although acoustic emission leak testing is potentially one of the best methods available for leak location, it is currently more often an art than a science.

Other Techniques

Additional methods for leak location have found limited application for underground heat distribution systems. Pressure or rate-of-pressure decay can be monitored continuously to indicate the presence of leaks, but accurate pinpointing is difficult. Linalog devices, or "pigs," are used to locate areas of excessive wall thinning caused by corrosion. However, there is no natural access to carrier pipes in these double-walled systems; the "pigs" would have to be introduced at points where sections of pipe wall had been cut out. Pipe bends at expansion loops would also pose a problem to passage of these devices.

Fluorescent-dyed liquid tracers, combined with photoelectric detection devices, have long been used for nondestructive leak detection. However, in underground piping systems, absorption or diffusion of the dye in the soil or inside the conduit would mask the actual leak locations.

Several electrical methods for detecting and locating leaks of conductive fluids in preinsulated systems

⁶C. Laske, D. Weimer, and H. V. Fuchs, "Aussichtreiche Versuche Zur Leckortung Mittels Korrelation (Promising Tests on Leak Detection by Means of Correlation)," *Gas Wasserfach Wasser Abwasser*, Vol 122, No. 3 (March 1981), pp 112-115.

have also been used.⁷ One system is based on measuring electrical resistance between an exposed conductor in the insulation and the carrier pipe. Leaks can be detected by measuring and comparing resistances at numerous points along the line. However, changes in conductor resistance caused by corrosion or breakage can occur over time and give erroneous readings. A similar system operates on the principle that an audio tone signal generated in the pipe will flow through the pipe whenever it can find a return path to ground. An insulated pipe will only allow the ground return to occur at a fault in the insulation. These methods are time-consuming, dependent on operator interpretation, and of limited use for long-term leak detection and location.

Another electrical technique is time-domain-reflectionometry, in which the outer braid of a coaxial cable laid inside the conduit is permeated by leaking fluid (high-temperature water or intruding groundwater). This changes the dielectric permittivity as well as the characteristic impedance at the leak. As the cable is pulsed by a generator, deviations of the characteristic impedance from its initial value will cause either reflected or standing waves to appear along the cable at the point of leakage. These waves are recorded and correlated to an integral multiple of the half-wave-length of the radio frequency pulse in the cable, allowing the leak to be located. Problems may again be encountered with corrosion of wire leads or impedance changes caused by humidity.

Other electrical methods that lack some of the shortcomings of the previously discussed techniques are not suitable for retrofit, so they are of little use for locating leaks in pipes that are already buried; however, in the future, they may find application in newly installed systems, but it is unlikely that the lifetime of these cables under the harsh underground conditions would be long enough to warrant their use. Their ability to detect multiple leaks is also dubious.

Some electrochemical techniques may be used to locate conduit leaks in buried systems. These methods are being investigated by the U.S. Army Construction Engineering Research Laboratory (USA-CERL).

Available Products and Services

Several companies manufacture systems and equipment useful for detecting and locating leaks in heat

distribution lines. Table 1 briefly outlines the types of services and equipment available, by manufacturer, and the prices of each.

4 REVIEW OF LEAK LOCATION SURVEYS

Leak Surveys

To obtain information on the performance of several types of leak detection systems, documentation from several applications of these systems was reviewed. This review revealed several drawbacks of the various systems as well as suggestions and observations made by operators in the field to make the use of these systems more effective.

Location of a Steam Leak Using Sonic and Infrared Techniques⁸

The U.S. Army Facilities Engineering Support Agency (FESA) documented an attempt at the Coast Guard Support Center, in Portsmouth, VA, to use ultrasonic and infrared methods to detect a leak in a double-walled line buried 4 to 12 ft (1.2 to 3.6 m) below the surface. All but about 50 ft (15 m) of the 500-ft (150-m)-long line was covered with a 12-in. (305-mm) concrete slab. However, background noise caused by steam escaping from the conduit in a nearby manhole masked the sound of the leak, rendering the ultrasonic technique useless.

An infrared leak search was conducted after sundown using a thermal imaging system. Temperature maxima were found at the condensate collection pit and at the leak position. The leak was determined to be a failure resulting from the torque exerted on the line when the supporting soil experienced excessive erosion.

Location of Water Leak Using Acoustic Emission⁹

FESA performed a leak location survey at Aliamanu Military Reservation in Fort Shafter, HI. The water leak portion of the survey showed a 23 percent loss of potable water, but leak positions were unknown.

⁸James F. Thompson, Jr., *Steam Leak Report for U.S. Coast Guard Support Center* (Facilities Engineering Support Agency [FESA], undated).

⁹James F. Thompson, Jr., *Aliamanu Military Reservation Water Leak Detection Survey* (FESA, December 1982).

⁷*A Survey of Leak Location Systems* (Raychem Corporation), pp 1-4.

Table 1
Survey of Available Products and Services

Company/Product/Service	Price of Base Unit	Date Priced
Infrared:		
<u>Product</u>		
Hughes Aircraft Company		
• Probeye Infrared Viewers	\$10K to 13K	(5/82)
• Probeye Thermal Video System	\$30K to 37K	(5/83)
Inframetrics		
• TV-Compatible Imaging Radiometers	\$24K to 51K	(7/81)
Xedar Sales Corp.		
• Infrared Camera	\$12.5K to 15K	(8/82)
• Infrared TV Camera System (Imaging)	\$24K to 34K	
Mikron Instrument Company		
• Infrared Thermometer	\$1.52K to 1.73K	(7/83)
AGA Corporation		
• Thermopoint 80 Manual Scanning Radiometer	\$2000	
• Thermovision 110 (Imaging System)	\$14K	(1/83)
• Thermovision 782 (Imaging System)	\$28K to 46K	
Barnes Engineering Company		
• Instatherm IR Thermometer	\$795 to 990	(1/82)
Standard Equipment Company		
• Secovision 220 Thermal Imaging/Recording System	\$14K to 19K	(6/83)
<u>Field Services</u>		
	Prices quoted for individual jobs.	
• Ricwil Pipeline Services Division (uses both infrared and acoustic emission to give a complete report)		
• Randolph & Associates (includes aerial IR inspection of 150,000 ft [45,000 m] of line, videotape and minimal interpretation, engineering, and recommendations)	\$10,000	(2/85)
Tracer Gas:		
<u>Product</u>		
Ion Track Instruments		
• Model 56 Leakgun	\$4153	(10/82)
• Model 61 Leakmeter II	6995	
Varian		
• Helium Spy 2000	\$11,295	(1/83)
<u>Field Services</u>		
• Heath Consultants: Two-Man Crew Per Day Plus Expenses	\$600	(3/84)
• Smith and Dennison: Two-Man Crew Per Day Plus Expenses	\$680	

Table 1 (Cont'd)

Company/Product/Service	Price of Base Unit	Date Priced
Acoustic Emission:		
<u>Product</u>		
Hewlett Packard		
• 4905A Ultrasonic Leak Detection System	\$1.215K	(8/83)
• 18100A Underground Leak Location System	\$3.765K	
Aqua-Tronics, Inc.		
• Model AT-2000 Water Witch	\$1.1K	(7/83)
Acoustic Emission Leak Locators, Inc.		
• AELL 1000-3000	\$5K to 25K	(10/82)
Fluid Conservation Systems		
• FCS 2000 Series Leak Location System	\$39K	
• Contract Work	\$100/hr plus equip.	(7/84)
• Lease of Equipment	\$1.65K/month	
Electrical:		
<u>Product</u>		
Goldak		
• Model 6800 Fault-Finder Pipe Tracer (Audio Tone Generator)	\$930	(7/82)
• Model FL 860 Fault Locator	\$1.675K	
Raychem		
• Trace Tek Systems (Resistance Measurement)	\$0.70 to \$2.00/ft of pipe	(12/84)
Perma-Pipe		
• PermAlert H (Time-Domain Reflectometer)	Prices quoted for individual systems.	

(It has been assumed that only a single pipe was present, i.e., no conduit). The manufacturer of the couplings between metal and plastic pipe stated that they had a 10-to-15-dB acoustic attenuation per coupling, rendering a normal 25-to-30 dB leak signal void in a fairly short length of pipe. Eight-in. (203-mm)-diameter plastic pipe was found to have an acoustic attenuation of about 40 dB per foot.

Seven waterline breaks were identified by an acoustic emission technique. An infrared technique located one leak where water pooled above-ground, but this method was abandoned since the constant ground temperature prevented measurement of a temperature differential between the ground surface and the leak environment. The FESA engineer suggested replacing all plastic water mains with cast iron or steel to give them greater strength and to facilitate the use of acoustic emission methods for future pipe leak location.

Leak Location Survey of HTHW and Steam Distribution Systems¹⁰

FESA performed an 8-day survey of 152 buildings and three central heating plants using acoustic and infrared leak location at Fort Gordon, GA. The tests revealed 12 HTHW system leaks, many of which occurred in expansion joints, in elbows, or at valves. Random measurement of HTHW supply, return, and conduit temperatures showed conduit temperatures ranging from 154° to 189° F (67 to 86° C). Such high temperatures were the result of gross insulation deterioration caused by flooded conduits. Sump pumps were either absent or inoperative. The HTHW system was buried 10 to 20 ft (3 to 6 m) below grade; thus,

¹⁰ James F. Thompson, Jr., *Leak Location Survey of High Temperature Hot Water and Steam Distribution Systems at Fort Gordon, GA* (FESA, July 1984).

lines were often placed directly in the water table. No cathodic protection was provided, allowing corrosion to progress unmitigated. Faulty welds containing slag were also identified as a possible cause of premature leaks. (Weld problems at Fort Gordon had been noted in an earlier survey of leaks.¹¹) The FESA engineers recommended replacing the conduit system with either an aboveground or a shallow concrete trench system to facilitate location and repair/replacement of leaking sections.

Field Inspection Techniques for Buried Steam Distribution Lines¹²

This study, conducted by the Navy, examined the use of tracer gas techniques to detect failures in the casing. Sulfur hexafluoride (SF₆) was used exclusively. With the ion-capture instrumentation used in this study, SF₆ was detectable in the parts per billion range. Ion-capture devices are less sensitive than gas chromatographs, but have shorter response times. Leaks were located by sampling the gas present in short lengths of polyvinyl/chloride (PVC) pipe driven into the ground above the pipe. (The sample hole nearest the leak should contain the highest concentration of gas, assuming direct vertical diffusion.) Tests were generally accurate with respect to the actual location of the leaks. The diffusion time for SF₆ in soil was found to depend on soil type, moisture content and packing density, pipe burial depth, leak size, and tracer gas concentration. The only parameter that the person conducting the leak survey can control is tracer gas concentration. A procedure for using this technique is outlined in the study documentation.

Casing Leak Detection Study¹³

To perform all controlled leak experiments well, the investigators in this study had to use three different tracer gases: SF₆, Freon 13B1, and Freon C-6 318. Different fill materials (sand, soil, mixed sand and soil, and concrete cover) and various geometries and locations of leaks (top, bottom, and conduit weld joint) were used to study the tracer gas effectiveness. The investigation produced the following conclusions:

¹¹ Ernest M. Honig and Robert A. Weber, *Analysis of Leaks in the High-Temperature Hot Water Piping System at Fort Gordon, GA*, Technical Report M-126/ADB009462L (U.S. Army Construction Engineering Research Laboratory [USACERL], 1976).

¹² W. Neboshynsky, *Field Inspection Techniques for Buried Steam Distribution Lines* (Naval Postgraduate School, June 1982).

¹³ P. L. Lagus and R. D. Broce, *Casing Leak Detection Study* (System, Science, and Software, July 1979).

1. Injecting metered amounts of compressed air doped with tracer gas of known initial concentration allows leak localization in many environments (generally to within $\pm 1/2$ depth of burial up to 42 in. [1067 mm]).

2. The use of multiple tracer gases increases the accuracy and credibility of the test results.

3. The tracer gas technique employed was found to be quite labor-intensive, since several persons were needed to sample gas concentrations simultaneously at various points along the line. It was therefore suggested that sampling be automated.

4. It was recognized that gas diffusion through soils is a complex process, and understanding and characterizing it would help locate leaks accurately. It was suggested that a computer analysis be used that would provide nomographs relating soil depth, type, compaction, water content, etc., to diffusion times.

Analysis

Locating leaks in conduit systems requires selecting the best location technique, given the constraints of the individual leak detection system; no one system will work optimally in every situation. It is likely that using several techniques together will yield the most accurate results.

5 LEAK DETECTION FLOWCHART

When leaks are known or suspected to exist in a prefabricated conduit underground heat distribution system, a logical series of steps can be taken to determine the best way to locate the leak(s). The simple flowchart provided in Figure 4 provides an effective scheme for selecting an optimal leak location method(s) for a specific situation and allows quick, cost-effective decisions to be made when seeking and evaluating system leaks. The search should begin with a pressure test of a conduit section between two manholes; one should then follow the flowchart for subsequent actions.

Decay of the air pressure in the conduit during the pressure test indicates a leak in the conduit wall. An infrared survey is then conducted; if it does not indicate the leak's position, a tracer gas survey is done. If the leak is located, the line is excavated at that point for repair or replacement. If the leak position is still

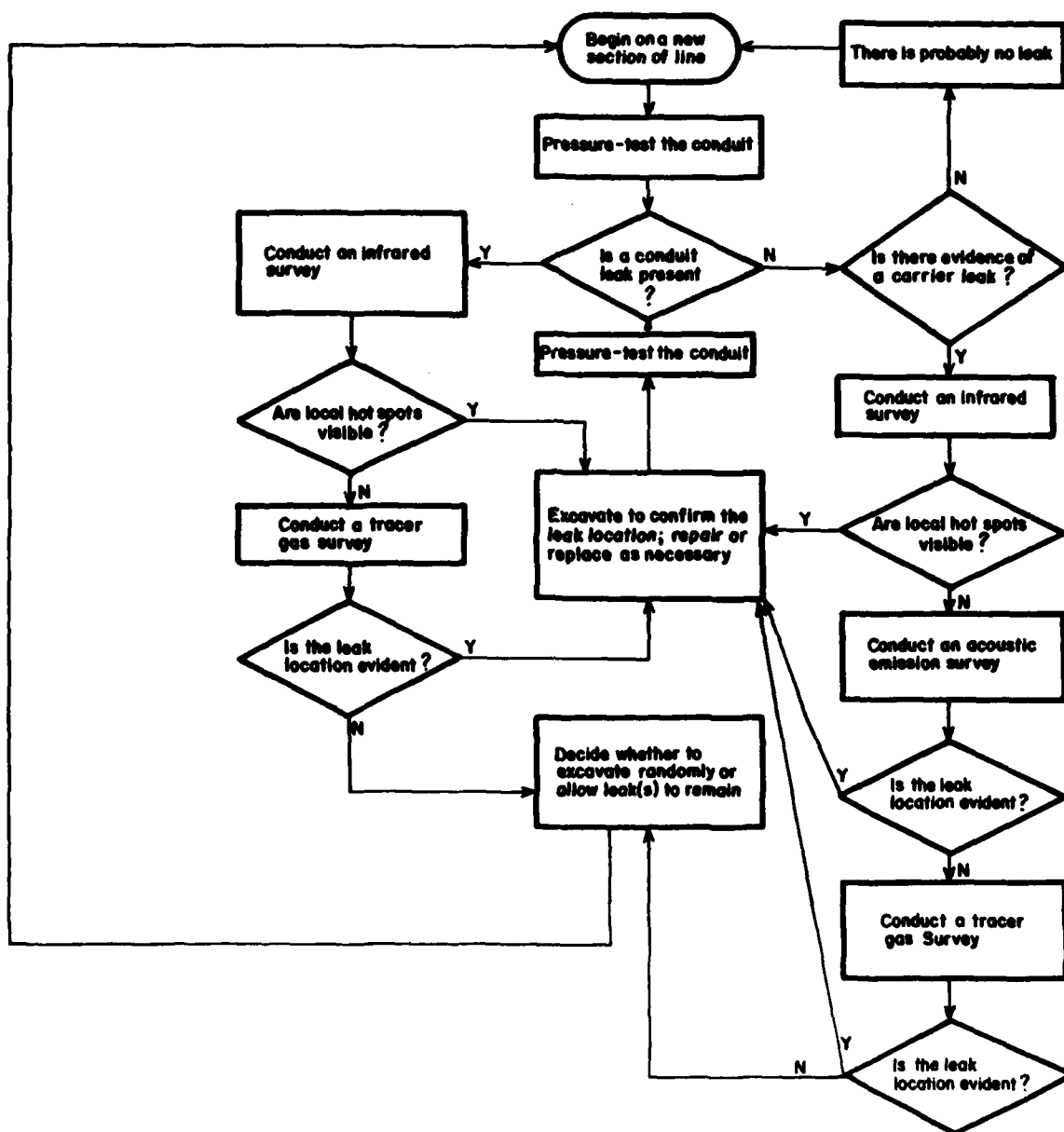


Figure 4. Decision flowchart for finding and evaluating heat distribution system leaks.

not known after application of these external techniques, operators must then decide on whether to conduct a random excavation or to allow the leak(s) to remain. A pressure test must be performed after repair to ensure that repair is complete.

Although there may be no indication of a conduit leak, there may still be carrier pipe leaks in a section of the line, as evidenced by feedwater losses, condensate losses, or other means. Infrared, acoustic emission, and tracer gas techniques should then be used (in that order) to help locate carrier pipe leaks. Again, conduit pressure tests must be performed on all repaired line prior to backfilling. If neither the conduit nor carrier pipe is obviously leaking in a given section, either there are no leaks in that section, or they are too small to be detected. In either case, they are of no concern at this time.

6 CONCLUSIONS AND RECOMMENDATIONS

This research has indicated that the problem of locating leaks in prefabricated steel conduit underground heat distribution systems is quite complex. Of the various methods reviewed, infrared spectroscopy, acoustic emission, and tracer gas seem to be the most effective techniques for locating leaks in existing prefabricated steel heat distribution systems.

Infrared spectroscopy is best used when a leak occurs in both the carrier and conduit pipes at the same location. It has the advantages of image manipulation, which makes leaks easier to see and interpret, and

does not require system shutdown to use. However, hot water from leaks that spreads to the surrounding soil may blur the image. Also, its accuracy is limited in many types of commonly occurring situations, and it is quite costly to use.

Acoustic emission methods have been employed successfully to locate leaks; however, they are expensive and require adequate personnel training.

Tracer gas techniques have already been successfully demonstrated in detecting leaks in underground telephone and high-voltage cables, and appear to be a suitable method for use in heat distribution line applications. However, they have several limitations: erroneous readings may occur because of gas diffusion rate differences, use of combustible gases may be prohibited because of their inherent explosion dangers, they are unable to detect multiple leaks, and the system must be shut down when these techniques are used.

Although techniques are available that will be able to provide detection/location for systems now under construction, many of them have serious drawbacks, most notably the inability to locate multiple leaks. Locating leaks in conduit systems requires selecting the best location technique, given the constraints of the individual leak detection system; no one system will work optimally in every situation. It is likely that using several techniques together will yield the most accurate results.

The flowchart provided in this report should be used to select appropriate leak location techniques. This will ensure that operators detect leaks as early as possible so that they can repair them promptly.

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